

***Lower Passaic River Sediment Pollution Study Using  
GIS, New Jersey, USA***

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### **Abstract**

The Passaic River is located in the New Jersey-New York metropolitan area. This river has been heavily polluted by dioxins, PAHs, PCBs and heavy metals due to agricultural, industrial activities, and urbanization. Contaminated sediments in the Passaic River have received considerable attention because contaminants (metals, PCBs, PAHs, dioxins) in the sediments have potential to release into the aquatic system and air through diffusion and/or volatilization, causing human health hazards. Identification of high concentration areas of these contaminants in the river-estuarine system is critical to the Passaic River environmental restoration and watershed protection. In this study, we analyzed portion of 10 years (1991-2000) data using Geographic Information Systems (GIS) as a tool to study the distributions of contaminants in the sediments. The results from this study provide important information for developing environmental management strategies for the lower Passaic River system.

### **1. Introduction**

The Passaic River is about 14 miles west to New York City, located in the New Jersey-New York metropolitan area. The Passaic River system consists of major and minor tributaries, and drains much or part of eight New Jersey counties as well portions of two New York counties and ultimately reaches Newark Bay at its confluence with the Hackensack River (Fig. 1). The drainage basin of northern New Jersey's Passaic River system covers approximately 2200 km<sup>2</sup>, about 11% of the state's surface area (NJDEP, 1987). The basin contains some of the most densely populated land in the nation and is afflicted with numerous environmental problems, including major industrial pollution and suburban sprawl. This river has been heavily polluted by dioxins, PAHs, PCBs and heavy metals due to industrial activities and urbanization.

The Passaic River environmental status is drawing much regional and national attention due to its urban environmental setting. The lower 6-mile reach of the Passaic River is one of EPA Superfund Sites (Fig. 1). In the lower Passaic River, fine-grained contaminated sediments have received considerable attention because these contaminants (metals, PCBs, PAHs, dioxins, etc.) have a potential to release into the aquatic system and air through diffusion, resuspension and/or evaporation, causing human health hazardous affect (Fu et al., 2001; Huntley et al., 1997; Walker et al., 1999; Wenning et al., 1994). Identification of these contaminant sources, "hot spots" and the factors controlling the distribution and accumulation of these contaminants in the river-estuarine system are not yet clearly addressed in a way that the results can be used to pinpoint

specific land-use practices, which presumably are the major causes of contamination. This study is designed to use available data with Geographic Information Systems (GIS) as a tool to study the distributions of contaminants in the sediments and address these issues of concern adequately.

## 2. Methodology

Since early 1990s, federal and NJ state agencies and private sectors have funded a series of remedial investigation of the lower six miles of the Passaic River to determine the horizontal and vertical distributions and concentrations of dioxins, pcbs, and metals in its sediment (Crawford et al., 1995; Finley et al., 1990; Hutley et al. 1995, 1997; Tierra Solutions, Inc., 2003; Wenning et al., 1993; Wolfskill and McNutt, 2000). Our present study area is in the six miles reach of the lower Passaic River, where is US EPA Superfund site (Fig. 1). The present study is mainly focused on analyzing the data from the 1995 RI-IWP Sampling program (e.g., R-EMAP, 1998), which includes taking 78 sediment core borings comprising of 3 borings taken along 26 equally spaced transects about 360 m apart, extending downstream from the 6 mile (or 9.6 km) study boundary (Fig. 1). The sampling dataset is being compiled and stored as a relational (i.e. all data in one table) database in Microsoft® Access 2000 that can be queried to extract specific sets of data to be analyzed and used with a geographic information system (GIS). The advantage of using a GIS system is the ability to view and analyze data spatially. GIS combined with the methods of geostatitics can be a very useful tool for managing, analyzing, and visualizing contaminant sediments in rivers, lakes, and harbors. ESRI Arcview® 3.2 GIS system is used to analyze the data and characterize the contaminant distribution in the lower Passaic River. Due to uncontrolled discharge of industrial waste water and sewage in the past, organic and inorganic pollutant, such as dioxin, PCBs, PAHs and heavy metals are present in this area. The parameters used in this study include dioxin, PAHs, PCBs and selected heavy metals.

## 3. Results and Discussion

The origin of these organic and inorganic contaminants are mainly from past industrial activities, oil spills and point-source release. Since the early 1900's the Passaic River has been degraded by oil spills, heavy metal pollution, coal tar/PAH pollution, sewage disposal, organic chemical spills, and sediment deposition and dredging activities. Many industries have bordered its shorelines including paper mills, petroleum plants, electroplating, and dye, paint, and chemical companies. (Cunningham, 1954; Hutley et al., 1997; Iannuzzi et al., 1997; Tierra Solutions, Inc., 2003; Walker et al., 1999). The results of selected contaminant concentrations and distributions found in this study are discussed below:

### 3.1 Dioxin

Dioxin is an anthropogenic toxic organic compound and is a general term that describes a group of hundreds of chemicals that are highly persistent in the environment (Fu et al., 2001; Finley et al, 1990; Gills et al, 1995). Dioxin could be formed by burning

chlorine-based chemical compounds with hydrocarbons. The major source of dioxin in the environment comes from waste-burning incinerators of various sorts and also from some point sources. The most toxic compound is 2,3,7,8-tetrachlorodibenzo-p-dioxin or TCDD (Finley et al., 1990; Wenning et al., 1993). Dioxin exposure has been linked to birth defects, decreased fertility, diabetes, learning disabilities, immune system suppression, lung problems, skin disorders, lowered testosterone levels and much more. Of all contaminants in the Passaic River sediments, dioxins have received the most attention. Dioxins are a short expression for polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). They are also persistent and lipophilic compounds that can be bioaccumulated and bioconcentrated in natural organisms and human bodies. Dioxins are both very toxic acutely and chronically and can be carcinogens. Of all congeners of dioxins 2,3,7,8 tetrachlorodibenzo-p-dioxin is the most toxic, persistent, and bioaccumulative (Fu et al., 2001; Wenning et al., 1992a).

Dioxin contamination in the lower Passaic River is especially of concern, which is under investigation by the EPA for evaluation of dioxins contaminants from a 2,4,5-T pesticide manufacturing company known as Diamond Alkali, now Occidental Corporation, as well as other non-point sources along the river (Huntley et al., 1995; Wenning et al., 1993). Huntley et al. (1995) found that heavily contaminated sediments from previous uncontrolled industrial discharge have been buried by relatively cleaner, recent sediments. However, sediment contamination nowadays is still present and may be caused by some point and non-point sources in the system. The variability of dioxin concentrations may be associated to various combined sewage overflows and diffuse sources such as stormwater runoff and the deposition of atmospheric combustion related activities (Crawford et al., 1995; Huntley et al., 1997).

In this study, we used EPA 1995 investigation data to map dioxin concentration in surface sediments ( $\leq 0.15$  meter i.e.  $\leq 0.5$  feet) in the lower Passaic River. It is found that dioxin concentration in surface sediments ranges from  $0.0788 \mu\text{g kg}^{-1}$  to  $72.3 \mu\text{g kg}^{-1}$  in the study area (Fig. 2). The highest concentration is found at a location within the Harrison Reach (mile point (mp) = 2, or km point = 3.2) of the study area

In this study, we investigated the transport of dioxin in the lower Passaic River. As the lower Passaic River is a tidal influenced estuary, using dioxin concentration in surface sediments to discern the long-term mass transport of dioxin could be skewed by sedimentation and vertical burials. Considering this factor, we use dioxin inventory in the sediments to study the along-channel dioxin transport. As an inventory of a contaminant is a vertical integration of the contaminant in the unit area, the estimation is not affected by the sedimentation rate and deep burials. We used three years data, which are 1991, 1993 and 1995, to evaluate the transport of dioxin with time. Based on our limited data, we found that dioxin inventory in the lower Passaic River ranges from  $0.0079$  to  $1.51 \mu\text{g cm}^{-2}$  for year of 1991,  $0.0012$  to  $2.91 \mu\text{g cm}^{-2}$  for year of 1993 and  $0.0004$  to  $228.9 \mu\text{g cm}^{-2}$  for year of 1995, respectively, and that high dioxin inventory seemed gradually moving down stream (Fig. 3). It should be pointed out that the 1995 sampling resulted in a relatively complete data set, which includes the data from cross section of the river and the data at depths. The 1991 and 1993 sampling did not cover as

broad area and depths as the 1995 sampling. Therefore, the inventories resulted from the 1991 and 1993 investigations can only represent the minimum inventory values. Nevertheless, the information from these inventory estimate still suggest that, as a result of hydrodynamics and sediment dynamics caused by fresh water discharge and tidal currents, the contaminated sediment has patch distributions and could be resuspended and gradually transported down stream.

### 3.2 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a group of over 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances. PAHs are usually found as a mixture containing two or more of these compounds (Lamoureux et al., 1996). Microorganisms can break down PAHs in soils, sediments or water after a period of weeks to months (Wenning et al., 1994). Through diffusive-exchange processes, gaseous PAHs can be emitted to air across the air-water interface (Nelson et al., 1998).

We studied PAHs distributions in surface sediments of the lower Passaic River based on the 1999 sampling data and found that total PAHs concentration ranges from 361 to 167000  $\mu\text{g kg}^{-1}$  with an average of 34070  $\mu\text{g kg}^{-1}$  (Fig. 4). High concentration of PAHs are found at mile point = 6 in the river. As discharge of contaminants to the river has been strictly controlled in recent years by federal and state regulations, these high concentrations of PAHs contaminants are very like the residuals from uncontrolled discharge in the past or accidental oil spills. But, the results indicate that PAH contamination in this area is still very serious and a remedial action is needed to recover the system (Gills et al., 1993).

### 3.3 Polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls (PCBs) are a group of 209 related compounds, which differ only in the number and pattern of chlorine atoms that are attached to the biphenyl molecule. These compounds are termed congeners of PCBs. The physical and chemical properties of PCBs show a gradation in increasing chlorination, with the more highly chlorinated congeners being the most fat soluble and the most stable (Wenning et al., 1994). Of the 209 congeners of PCBs, a small number, less than 10% of the total, have been reported as having toxicological effects (Danse et al., 1997; Longnecker et al., 1997). As same as dioxin, the problem with PCBs is that their presence in the environment is ubiquitous and compounds degrade very slowly (Lamoureux et al., 1996).

In this study, we only finished analyzing total PCB data for the 1995 sampling. Data shows that the concentrations of total PCBs concentration in the lower Passaic River surface sediment ranges from 76.1 to 17200  $\mu\text{g kg}^{-1}$  with an average of 1713  $\mu\text{g kg}^{-1}$  (Fig. 5). The high total PCB concentrations are found at mile point ~2 and 5 (km point ~3 and 8), respectively (Fig. 5).

### 3.4 Selected Heavy Metals (, Cr, Hg, Pb, Zn)

Heavy metal contamination in the lower Passaic River is also of big concern because of these toxic metals directly affect water and sediment quality and aquatic life. The knowledge of metal contamination in the lower Passaic River is critical to the decision-making of Passaic River ecosystem restoration. In this study, we only performed data analysis for 1995 sampling. Heavy metal contaminant (Cr, Hg, Pb and Zn) distributions surface sediments in six miles of the lower Passaic River are shown in Figs. 6-9. We found that Cr concentration ranges from  $\mu\text{g kg}^{-1}$ , 7900 to 58900  $\mu\text{g kg}^{-1}$  (Fig. 6), Hg, 100 to 10700  $\mu\text{g kg}^{-1}$  (Fig. 7), Pb, 4400 to 751000  $\mu\text{g kg}^{-1}$  (Fig. 8), and Zn, 20500 to 1620000  $\mu\text{g kg}^{-1}$  (Fig. 9), respectively. High concentration areas of these toxic metal contaminants are focused within Harrison reach in mile point 2 to 3 (or km point 3 to 5) of the study area. As there were and are numerous of industrial manufactures situated on the both side of the lower Passaic River, they are sources of these contaminants (Bonnievie et al., 1992, 1993, 1994; Crawford et al., 1995; Gills et al, 1993; Huntley et al., 1997) . This is especially true in the past when the discharge of various contaminants to the Passaic River system is uncontrolled and unlimited (Huntley et al., 1995; Iannuzzi and Wenning, 1995; Iannuzzi et al., 1997; Meyserson et al., 1981).

### Summary and Recommendation

Analyzing the existing large data sets, our research shows that the lower Passaic River is still one of the nation's most polluted rivers and estuaries. Remediation and restoration actions are needed to recover the system. This study demonstrates that Geographic Information System (GIS) analysis of contaminant data not only enhances the characterization of the contaminant spatial distribution, but also serves as an informative management tool to provide important information for the strategic development of environmental management and restoration.

For the future work, our preliminary data analysis suggests that an in-depth understanding of the source, transport and fate of these contaminants be necessary for effective environmental management and ecosystem restoration of the lower Passaic River. As found in this study, some critical data at depths are missing. These data are important and useful for precise analysis of contaminant focusing sites and accurate estimate of contaminant loads. Therefore, a comprehensive review, analysis and assessment of contaminant data, including further data collection, are recommended by this study. After a more comprehensive study is done, an integrated information and better understanding of the lower Passaic River environmental status will be achieved.

### Acknowledgement

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Figure 1. Map showing the study area in the lower Passaic River, New Jersey.

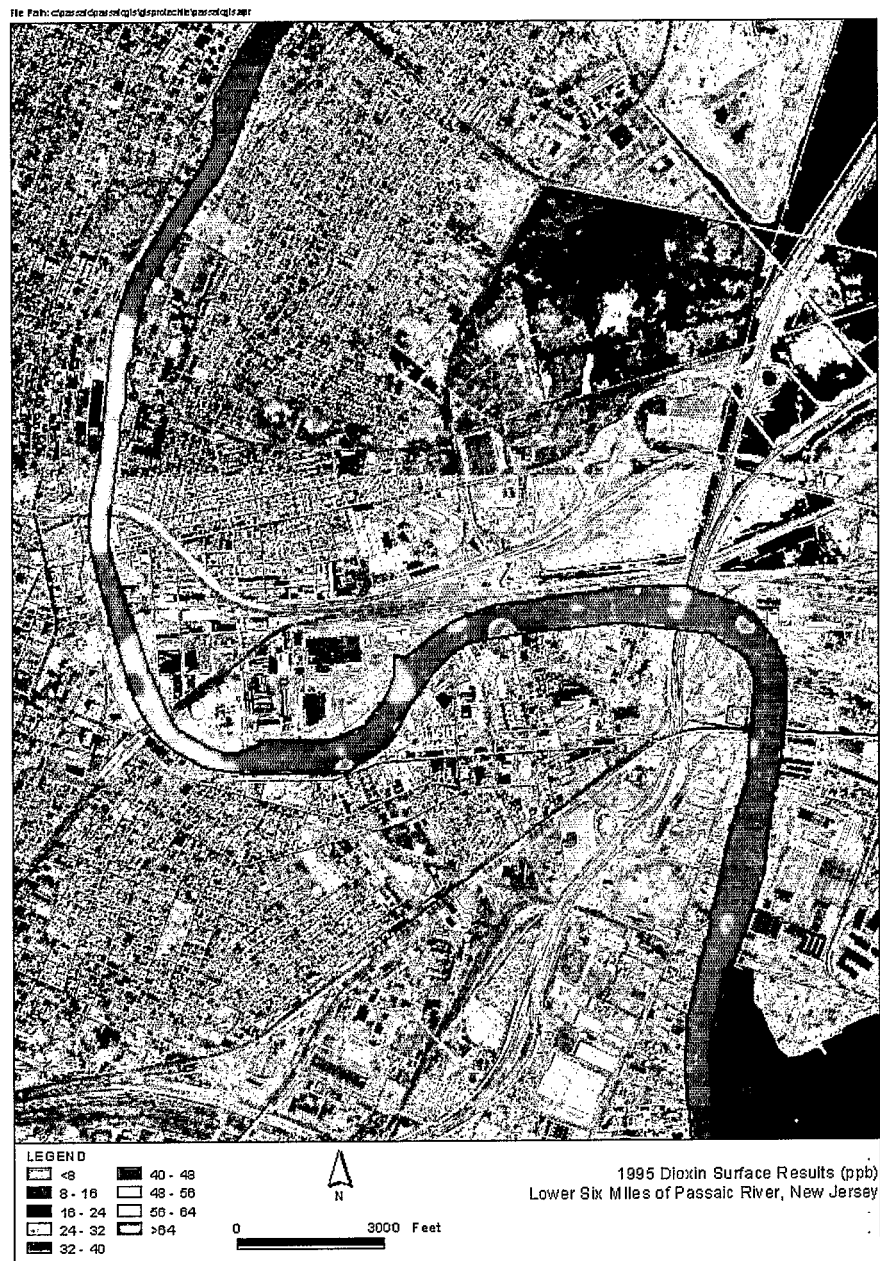


Figure 2. Dioxin concentration in the surface sediments of the lower Passaic River. Data are in courtesy of US EPA1995 investigation.



Figure 4. Total PAHs concentration in the surface sediments of the lower Passaic River. Data are in courtesy of the 1999 investigations.

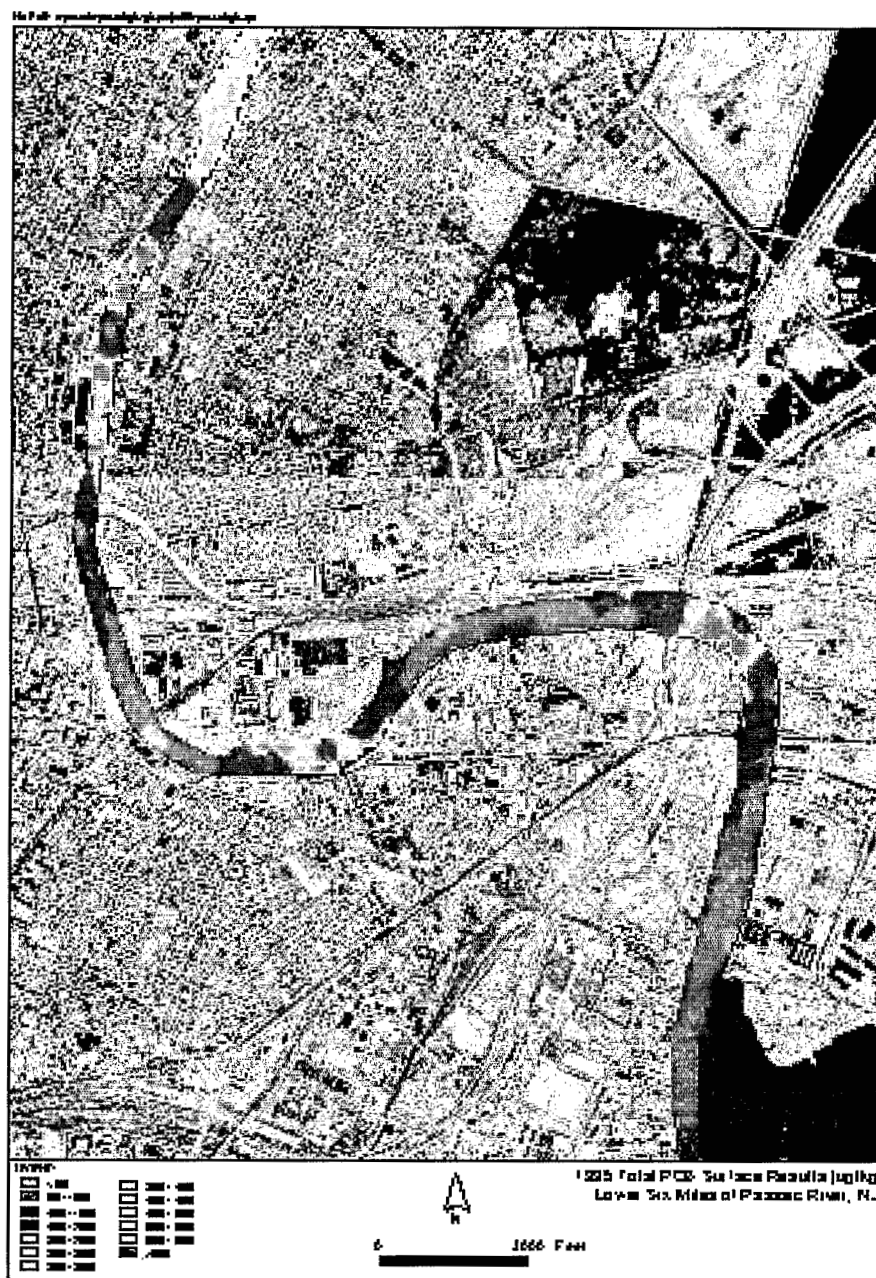


Figure 5. Total PCBs concentration in the surface sediments of the lower Passaic River. Data are in courtesy of US EPA 1995 investigations.





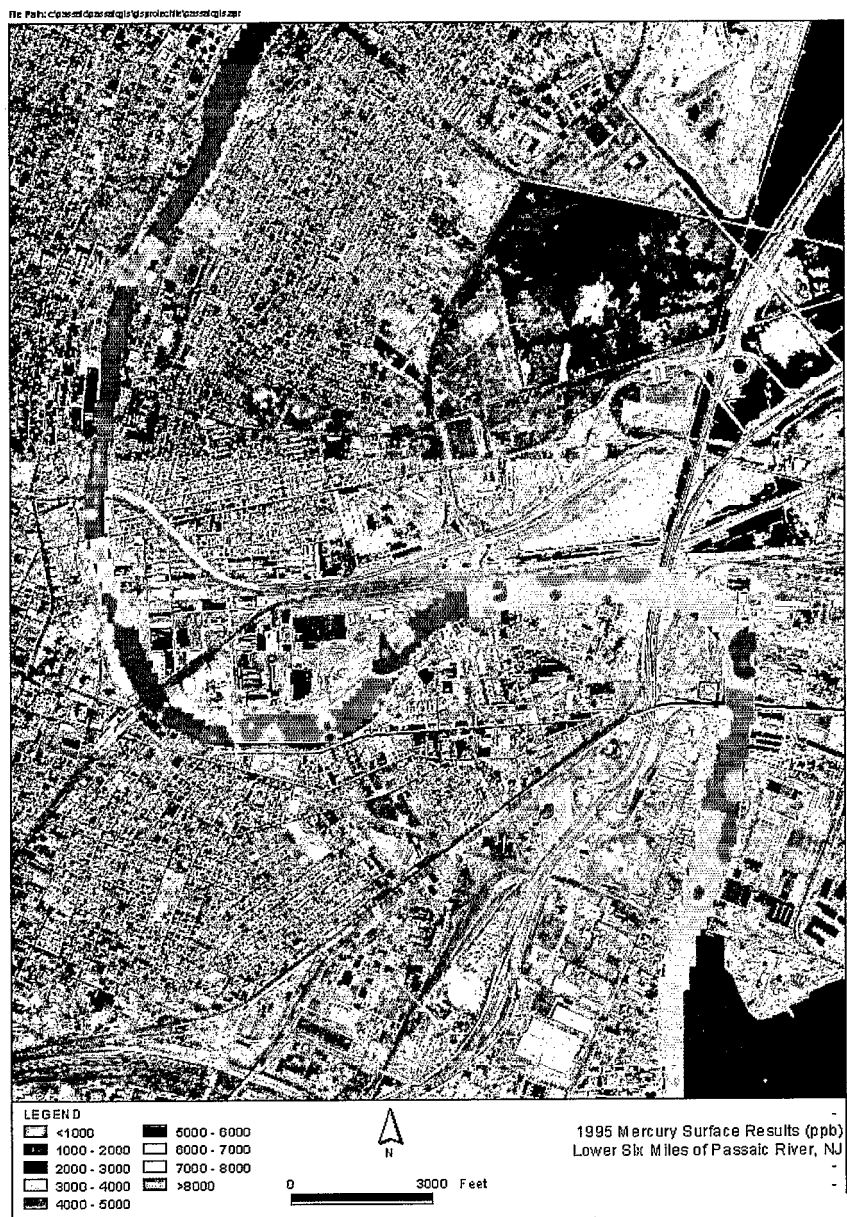


Figure 7. Mercury (Hg) concentration in the surface sediments of the lower Passaic River. Data are in courtesy of US EPA1995 investigations.



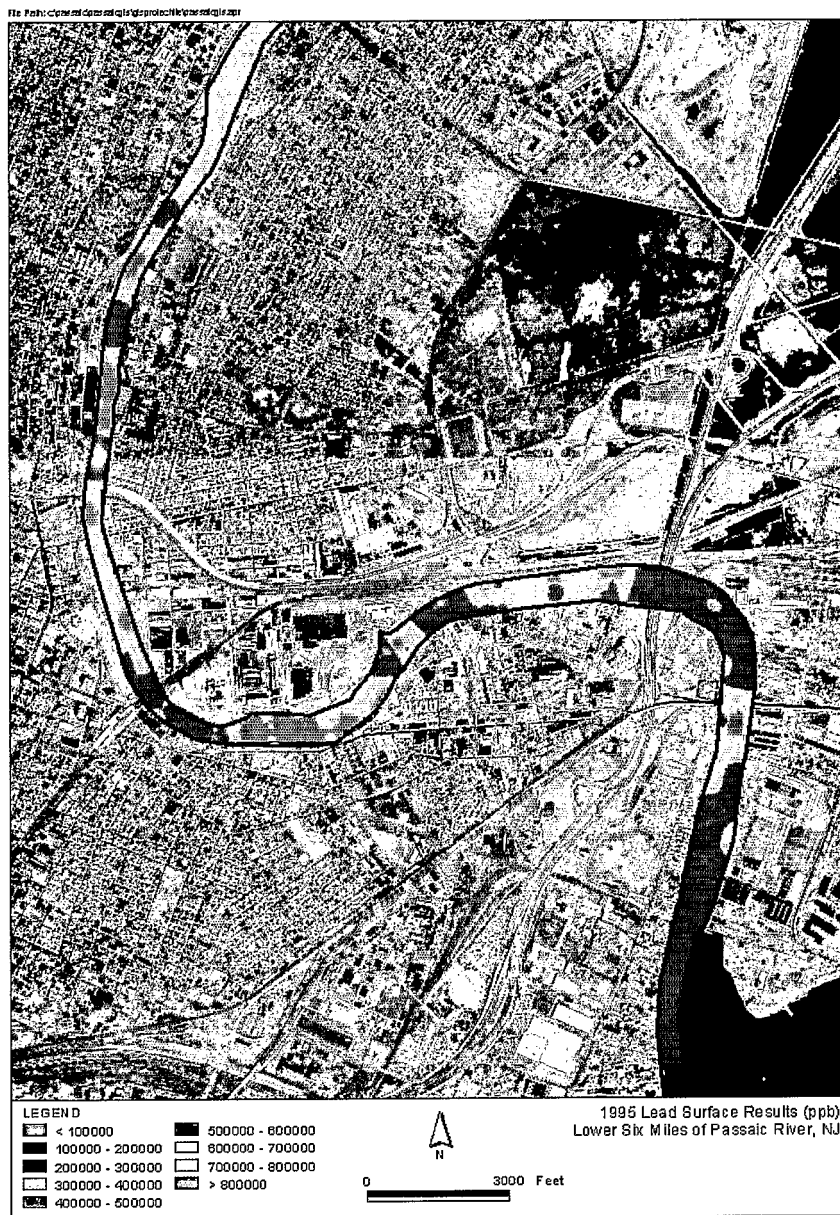


Figure 8. Lead (Pb) concentration in the surface sediments of the lower Passaic River. Data are in courtesy of US EPA1995 investigations.

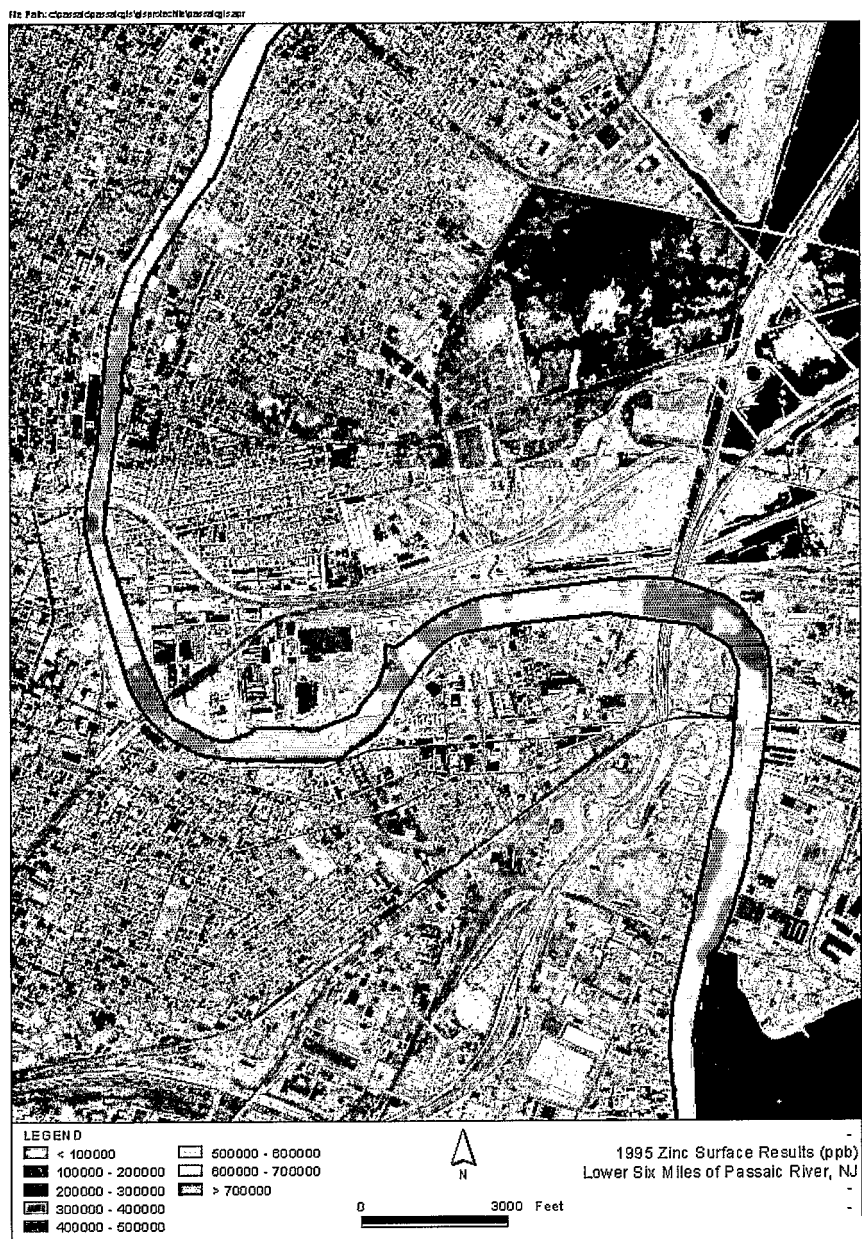


Figure 9. Zinc (Zn) concentration in the surface sediments of the lower Passaic River. Data are in courtesy of US EPA1995 investigations.